Characterization of Electric Charge Density using Electrophoretic Mobility for Studying Electrophoretic and Twisting Ball Displays

-Preparation and Characterization of Bichromal Particles for Twisting Ball Display-

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Abstract

Electrophoretic image displays and electrical twisting ball displays are the most promising candidates for Digital Paper. In the case of electrophoretic displays, their display elements consist of microcapsules that contain either negatively charged black or positively charged white particles (opposite pair of polarities are certainly allowed). Depending on the electric field applied, the particles migrate toward the top or bottom of the display. Electrical twisting ball displays consist of tiny balls whose surfaces are divided into two areas with different electric charges and colors (usually black and white). The electric field determines which side of each ball rotates upward. In both cases, the patterns of black and white can create letters, words and images.

The key technology of these two systems is the difference in electric charge density of the display elements since this forms the force driving display element migration/rotation. Therefore, quantification of electric charge density is considered to be essential for controlling these systems. We define electrophoretic mobility as the parameter of electric charge density and study how the electric charge density influences the motion of the display elements using this parameter.

We will also report a new method for preparing balls in twisting ball displays.

1. Introduction

The concept of Digital Paper[1] (or Electronic Paper) was recently proposed as an ideal medium that combines the both advantages of hardcopy and softcopy. In this research, we have focused on the electrophoretic display and the twisting ball display among the known candidate technologies for Digital Paper.

The principle of the Electrophoretic display is shown in Figure 1. The basic constituents are a dielectric liquid and minute white and black particles packed into many microcapsules. These white and black particles move in opposite directions across the sheet medium depending the polarity of the electric field applied across the sheet. The result is the formation of a black and white image on the sheet.[2]

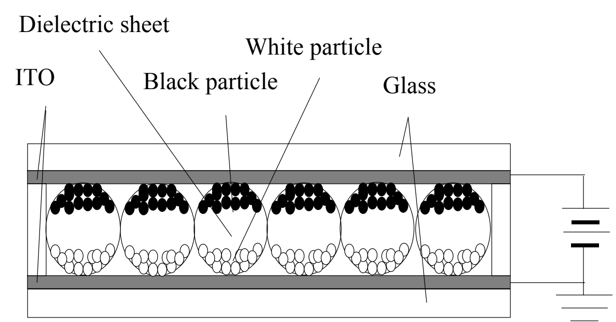

Figure 1. Structure of electrophoretic display

The principle of the twisting ball display is shown in Figure 2. It consists of balls with black and white hemispheres that float in a dielectric-liquid. Individual balls are held in cavities formed in a transparent dielectric polymer sheet. The balls can be rotated by setting electric fields across the sheet. Images are formed by setting the appropriate electric field pattern on the display sheet.[3]

Both imaging systems use the principle of electrophoresis to drive particle migration or ball rotation. We focus on the latter and our view is that ball rotation can be explained as the result of force pair, each of which works at one hemisphere so as to force movement to the opposite direction. The design principle based on this viewpoint was tested as follows. A material pair was selected that offered opposing electrophoretic movement. Balls were constructed as using the material pairs. Behavior of ball rotation was tested to see if it confirmed the expected movement characteristics. A novel method of ball production was proposed, and rotation behavior was confirmed.

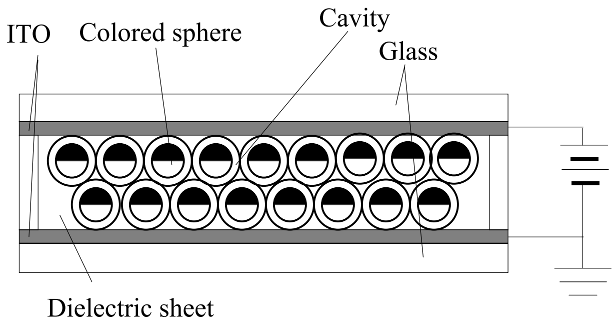

Figure 2. Structure of twisting ball display

2. Chemical Formation of Twisting Balls

The twisting balls were fabricated as follows. Three liquids with different colors with different electric properties were prepared; their compositions are given in Table 3. Liquids A and B were dropped into the air from syringes and the resulting droplets fuse into one due to their surface energy. The compound droplet fell into liquid C as shown in Figure 3. The chemical reaction between the sodium alginic acid in liquids A and B and calcium chloride in liquid C formed an insoluble layer of calcium alginic acid on the surface of each droplet. After drying, the droplets became balls with hemispheres of different colors and electric properties. Their surfaces were covered with an insoluble layer.

Some of the balls were immersed in a 0.1 M Ethylenediamine-N,N,N',N'-tetraacetic acid (EDTA) solution for 60 minutes in order to remove their surface layer of calcium alginic acid. The resulting twisting balls have diameters of 2-3 mm and bare hemispheres with different colors and electric properties (See Figures 4 and 5).

We have also found that very tiny twisting balls, diameters of 30 μm, can be prepared by using sprays instead of syringes.

Table 1. Compositions of Liquids

	Liquid A	Liquid B	Liquid C
Composition	Sodium alginic acid Silica pigment Red pigment Water	Sodium alginic acid Plastic pigment Water	Calcium chloride Water
Electric charge	+	—	+
Color	Red	White	Transparent

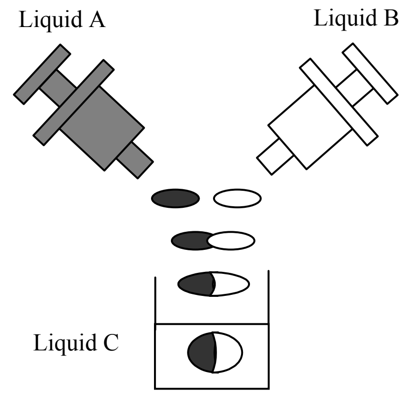

Figure 3. Schematic diagram of ball formation

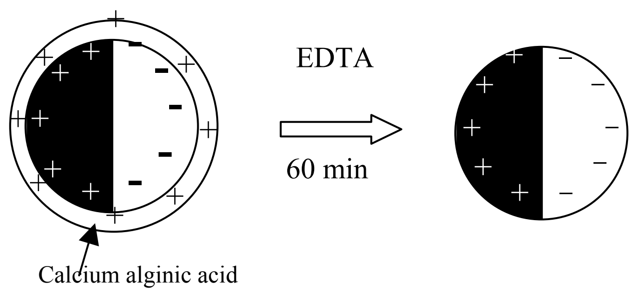

Figure 4. Schematic diagram showing removal of calcium alginic acid from a ball

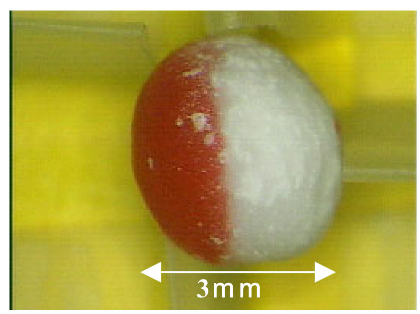

Figure 5. Optical microscope image of twisting ball

3. Experiments

3.1. Measurement of Monochromal Ball Mobility

3.1.1. Experimental Method

Mobility was calculated from the measured velocities v of four types of monochromal balls in a cell under applied electric field E.[4] The cell, illustrated in Figure 6, was filled with two immiscible dielectric liquids with different specific gravities. The liquids used were hydrocarbon Isoper-G (specific gravity 0.75) and hydro fluoride PF5052 (specific gravity 1.70). The balls floated at the boundary of the two liquids, and a driving voltage was applied to the electrodes set at the ends of the cell. The monochromal balls tested were made with either[7] Liquid A or Liquid B with two treatments: coated with calcium alginic acid (original) and non-coated (immersed in ETDA).

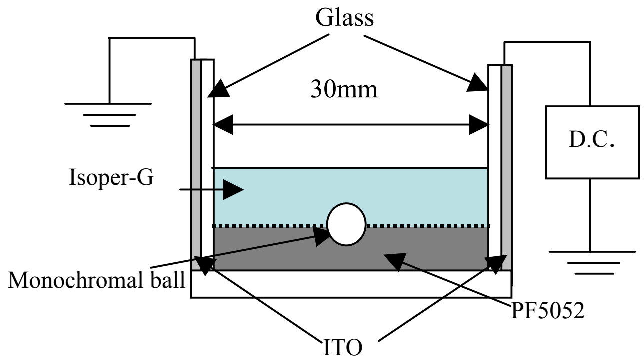

Figure 6. Experimental apparatus for measuring ball mobility

3.1.2. Results of Mobility Measurements

The measured migration velocities are shown in Figure 7. Mobility μ was calculated from the inclination of the fitted lines. The calculated results are summarized in Table 2. Only the uncoated balls made with liquid B showed negative mobility.

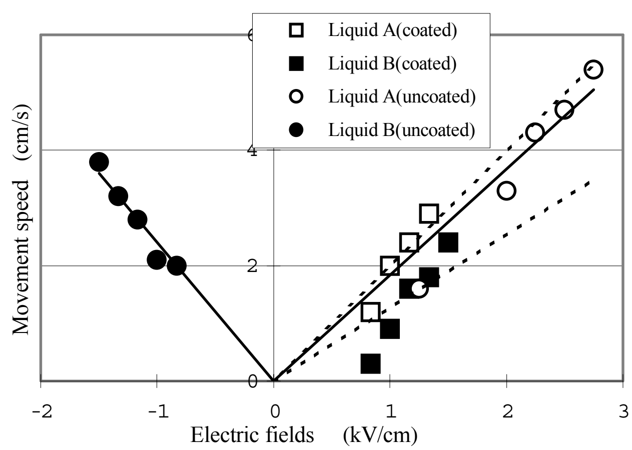

Figure 7. Measured migration velocities of four ball types

Table 2. Measured Ball Mobility

Monochromal ball		Mobility μ ($\times10^{-7}m^2/Vs$)	Mobility difference μ ($\times10^{-7}$ m^2/Vs)
Content	Coating		
Liquid A	Coated	+1.98	0.70
Liquid B		+1.28	
Liquid A	Uncoated	+1.86	4.26
Liquid B		–2.40	

3.2. Evaluation of Ball Rotation Behavior

3.2.1. Experimental Method

The rotation behaviors of two bichromal balls (coated and uncoated) were tested in a cell whose driving electrodes were vertically separated by 9 mm as shown in Figure 8. Each test ball sample was floated at the boundary of the two liquids using the same liquids used in the prior experiment. The balls were 2mm in diameter. An electric field was applied between the two electrodes and ball rotation behavior was observed.

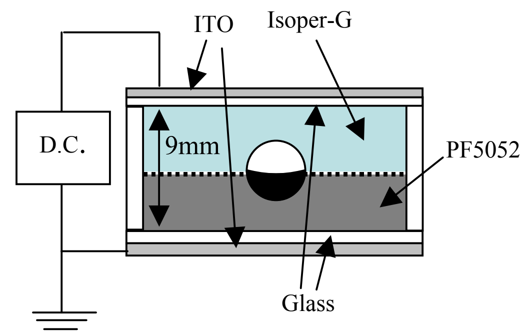

Figure 8. Experimental apparatus for examining ball rotation

3.2.2. Results

The observed rotation behavior is summarized in Table 3. Uncoated balls yielded ideal rotation behavior. Coated balls, on the other hand, showed only very weak rotation and strong migration.

Table 3. Observed Behavior of Bichromal Balls

Ball type	Mobility Δμ ($\times10^{-7}$ m^2/Vs)	Applied electric field (kV/cm)	Ball behavior
Coated	0.70	5.00	Migration is dominant with weak rotation
Uncoated	4.26	5.00	Rotation is dominant

4. Discussion

The results of the ball rotation measurements confirm our expectation: ideal rotation is realized by combining two materials with a large difference in mobility as measured using monochromal material balls.[5] The surface of the coated ball should be removed; the combination of the two different materials is not effective in such a ball. The surface of the uncoated balls is, on the other hand, consist of two expected materials with large difference of mobilities. This is considered to be the reason of the results shown in Table 3.

5. Summary

(1) The twisting ball display was studied as an example of a display system based on the electrophoretic phenomenon. Our assumption was that ball rotation characteristics could be determined from the measured electrophoretic movement behavior of the different materials constituting the balls.
(2) A novel method of producing balls was described: the agglomeration of two free-falling drops of different materials produced ideal bichromal balls.
(3) The rotation behavior of one bichromal ball type was tested and the expected rotation characteristics, that agreed our assumption, were seen.

Further study using ink jet nozzles are now being planned with the goal of improving ball production rates and decreasing ball size.

Reference

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Biography

Keisuke Ichikawa was born in 1979. He received his B.S. degree in 2002 from Tokai University. He is expected to receive his M.S. degree from Graduate School of Tokai University in 2004. He is now studying the twisting ball display and electrophoretic display.